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# Assessment of Resting Force and Stiffness of Bucco-Facial Tissue in Adolescents

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# The Assessment of Resting Force and Stiffness of Bucco-Facial Tissue in Adolescents

by

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## Introduction

The tooth, approximated by muscle and other soft tissue which is functioning buccal or lingual to it, generates active and reactive forces. The equilibrium position of a tooth (and to extend this further - a dentition), therefore, is somehow related to a resultant of all forces and moments developed. In normally active humans, oral musculature is in a positive state (minimal activity) a great portion of the time, and these soft tissue components of the face and oral cavity can be considered "at rest".

One of the physical properties of muscle tissue is its "elasticity" a quality bioengineers call stiffness. This specific elastic quality is useful when determining the change in the magnitude of force developed by the muscle as it is displaced.

It is of particular importance to an orthodontist to be able to anticipate the level of dentition stability when orthodontic therapy either expands or constricts arch widths. The oro-facial musculature and associated soft tissue influences tooth position. The extent to which this influence is exerted has not been recorded accurately.

In order to better understand the influence of the buccal musculature and associated soft tissues on the posterior teeth, both the "resting forces" and the elastic properties of these tissues must be accurately quantified. Prior to the present study, the instrumentation utilized to assess muscle force possessed various disadvantages, hence accurate recording of forces could not be accomplished. The main thrust of this study, therefore, was to quantify the forces generated by the lateral wall of the oral cavity at both resting and extended positions. In particular, evaluation was made of those buccal tissues, including the buccinator muscle in the region of the interocclusal space as representative of lingually directed forces exerted upon the maxillary and mandibular molar-premolar region. A group of adolescents 12-16 years of age participated in the study. The instrumentation utilized was capable of assessing forces delivered by the buccal tissue with a higher degree of accuracy than previous investigative instrumentation.

In addition, the study attempted to 1) assess the energy dissipation represented by force-displacement hysteresis, a quality possessed by viscoelastic materials and 2) assess the influence of head posture extension upon tissue stiffness.

## Review of Literature

Utilizing the same instrumentation described in an earlier report, Lear (1967) studied seven 18-32 year old male students to assess the stability of normal occlusions based upon the supposition that there is a counterbalancing of buccal and lingual forces. Measurements were recorded in the molar-premolar region. Force levels were determined for speech, mastication, swallowing, and rest position. Forces were measured in terms of gram-minutes because the authors assumed that the effective force produced by a specified activity, on tooth position, was related to magnitude of its daily duration. The results were recorded as minutes per day of activity. Projected 24 hour buccal forces during rest ranged from 500 gram-minutes to 1250 gram-minutes. For head erect posture a mean of 147 gram-minutes were recorded.

Jacobs (1967) reported that high IMA (index of muscular accomodation) values were associated with excessive overjet and overbite, and that repositioning of anterior teeth would result in a decrease of the IMA (7.8 to 1.7). He concluded that there was a significant decrease of maxillary tonic and mandibular contractile forces. Force values were assessed via strain gauge transducer instrumentation.

In a study of 19 young adult males, Proffit, et al. (1964) compared pressure patterns in a small group of persons who possessed malocclusions with those of "normal" dentitions. Tongue and lip pressures were recorded against the dentition during swallowing. Strain gauge pressure transducers were placed in order to simultaneously record forces: 1) labial to maxillary central incisors; 2) lingual to the maxillary centrals in occlusion; 3) lingual to the maxillary first molar. A mercury strain gauge was utilized as a swallowing indicator. The mean maxillary pressure during swallowing in the lip area was 32.5 gm/cm$^2$; the anterior tongue area was 40.8 gm/cm$^2$; and the lateral tongue area was 42.8 gm/cm$^2$.

Gould and Picton (1962) used seven subjects to assess resting forces of the lip and cheek musculature. Abnormal force levels such as produced by blowing and swallowing were also assessed. The average resting force perceived via strain gauges from the buccal musculature was 15 gm/cm$^2$.

A transducer system was devised by Lear, et al. (1965) to record lateral forces directed on the dentition. The device was utilized to assess mean force/time. Electronic integration was employed to analyze the data.

Testing of threshold levels of forces necessary to displace teeth (Lear, et al. 1972) demonstrated that from 0.9 - 1.0 grams of force were necessary to displace a premolar 1.25 micrometers or greater for a period of 100 milliseconds. As the duration of force decreased, larger force values were necessary for the required tooth displacement. The objective of the study was to demonstrate that the magnitude of buccal forces exerted by musculature is sufficient to displace the tooth.

Etzelmiller (1963), utilizing a lever principle device, concluded that the resting force exerted on the maxillary premolar by the buccal musculature ranged from 1.0 - 10.5 grams with a mean of 5.33 grams. He also found that there was no difference in resting force levels between males and females. In addition, the stiffness factor ranged from 0.204 gm/mm to 1.612 gm/mm with a mean of 0.840 gm/mm and that no difference existed between sexes.

Harmon (1966) concluded that a measurable tooth movement can be accomplished by generating a soft tissue force with a 2 mm extension from the tooth into the buccal musculature. In addition, the magnitude of force necessary to initiate cellular activity in tooth movement can be very small. Moreover, arch continuity is a factor in the stability of teeth, and forces from one arch may be transmitted to the opposing arch.

In considering various anatomic and physiologic parameters which determine the magnitude of force exerted upon the dentition by buccal musculature, Jacobs and Brodie (1966) found that the maxillary tonic pressures are three times as high as those in the mandible. They utilized strain-gauge transducers to measure oral vestibular forces acting upon the teeth.

O'Meara (1962) utilizing methodology similar to Attaway (1961) concluded that "forces generated by the perioral and lingual musculature are significant factors in determining the position of bicuspid teeth."

In a study designed to compare lip and tongue pressures between Australian Aboriginals and American subjects Proffit (1975) demonstrated mandibular labial resting pressures of approximately 16 $gm/cm^2$ in the American subjects.

Solow and Tallgren (1976) found a significant correlation of the position of the head in relation to the cervical column with craniofacial morphology. Extension of the head in relation to the cervical column was found related to large anterior and small posterior facial heights, small antero-posterior craniofacial dimensions, large inclination of the mandible to the anterior cranial base and to the nasal plane, facial retrognathism, a large cranial base angle, and a small nasopharyngeal space.

## Materials and Methods

A group of seven individuals participated in the study. The ages ranged between 12 years - 6 months and 16 years - 0 months. The maturation stage of each individual was assessed by a questionnaire listing secondary sex characteristics, family history, and longitudinal height data. All possessed an Angle Class I molar relationship. Clinical assessment of the profile was established.

| Sample Number | Age | Sex | Profile |
|---|---|---|---|
| 1 | 16 | F | orthognathic |
| 2 | 16 | M | retrognathic |
| 3 | 15 | M | retrognathic |
| 4 | 12 | F | orthognathic |
| 5 | 12 | M | orthognathic |
| 6 | 12 | M | orthognathic |
| 7 | 12-6 | M | orthognathic |

The instrumentation system utilized for the study was one which had been developed by Bowley, Weinstein, Hapala, and Boyle. This system combines both hydraulic and strain gauge technics. The major advantage of this type of instrumentation is that it is capable of monitoring both force and displacement with time. Other investigators (Proffit, 1964; Feldstein, 1950; Winders, 1962) have utilized either hydraulics or strain gauge technics to determine force levels.

The hydraulic aspect of the system is utilized to measure the forces at a given displacement of the cheek. A slave bellows (Servometer Corporation, Model #22883) is an electroformed nickel bellows which acts as a hydraulic piston. An acrylic button is attached to the free end of the bellows. The cross-sectional area of the button approximated the contacting surface area of the crown of a bicuspid tooth (approximately 12 $mm^2$). The assembly is then mounted upon an individually constructed removable maxillary acrylic appliance which is positioned in the subject's mouth on the maxillary dentition (Figure 1). The slave bellows is activated

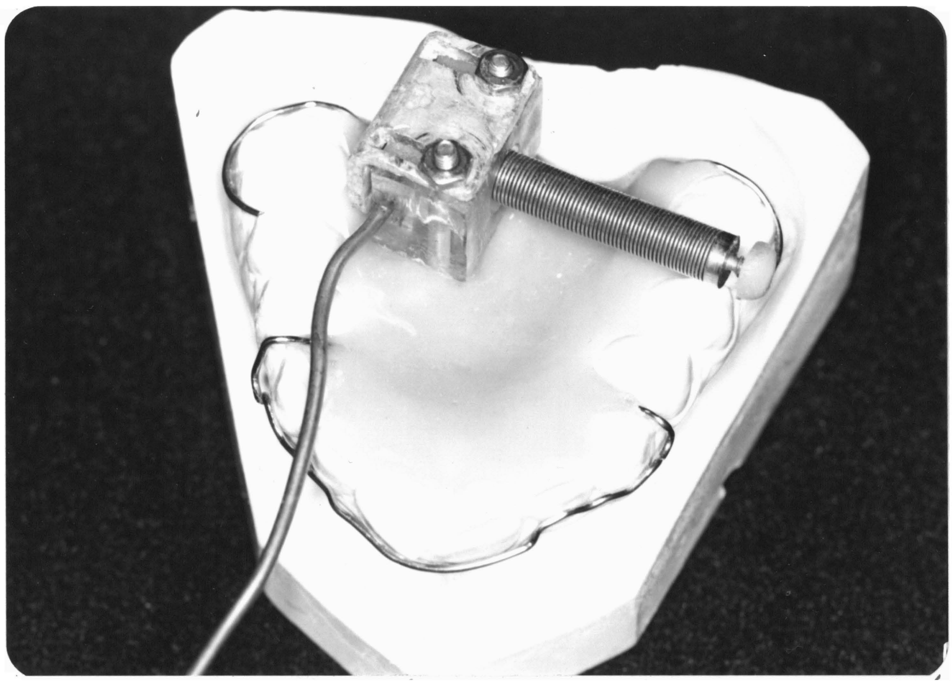


FIGURE 1

by a master bellows (Servometer Corporation, Model #22883) to deliver a given force which results in a measurable displacement (Figure 2,A). The master bellows also acts as a hydraulic piston to deliver a given force. It is connected to the slave bellows by a semi-flexible soft stainless steel tube. The master bellows is activated by a torque motor which is controlled by an analog controller. Incorporated within the master bellows is a LVDT type pressure transducer (Schaevitz Corporation PTA-114A) capable of measuring fluid pressure via an electrical signal (Figure 2,B). This is used to record the force delivered by the cheek. A LVDT (linear variable differential transducer) is a device which transforms displacement into a linearly varying voltage (Figure 3) and, therefore, will measure displacement at the master bellows. A Ross Control Corporation "Computer Automator" is utilized for data acquisition and calibration.

The instrumentation (Figure 4) in spite of its sophistication, presented two problems. First, there exist non-linearities inherent in an actual bellows (hydraulic) system. Forces and displacements are not easily determined as in a linear system because of compressibilities of the actual system.

The first problem is solved by obtaining static calibration curves which yield both force and displacement as a function of LVDT and pressure transducer output.

The calibration apparatus (Figure 5) is fabricated in order that a known axial load may be placed upon the slave bellows. Displacement is simultaneously obtained by adjusting the position of the bellows with a micrometer. For increasing loads, the slave bellows

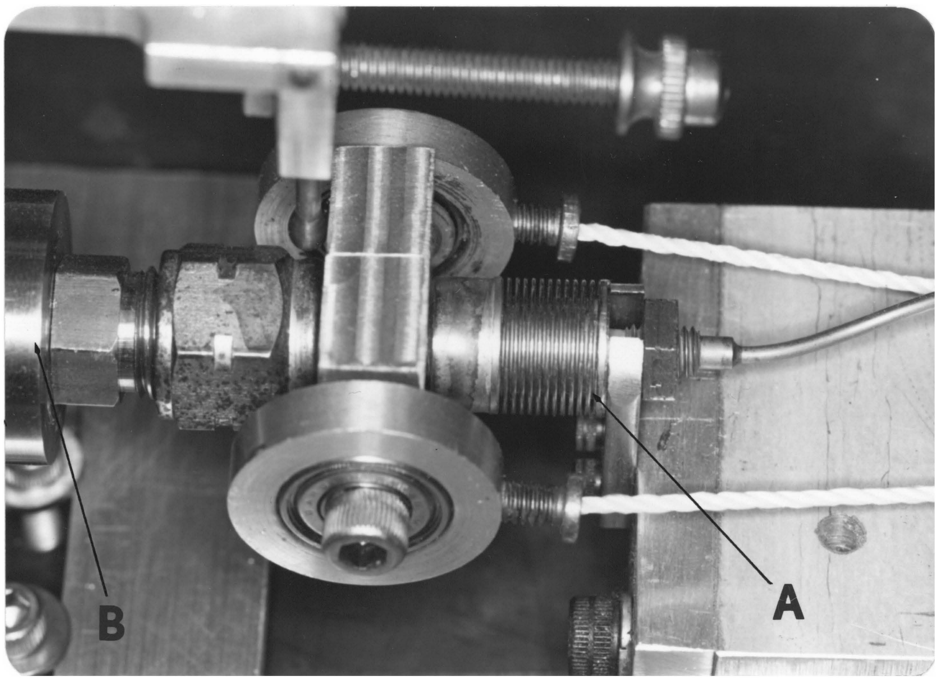



FIGURE 2

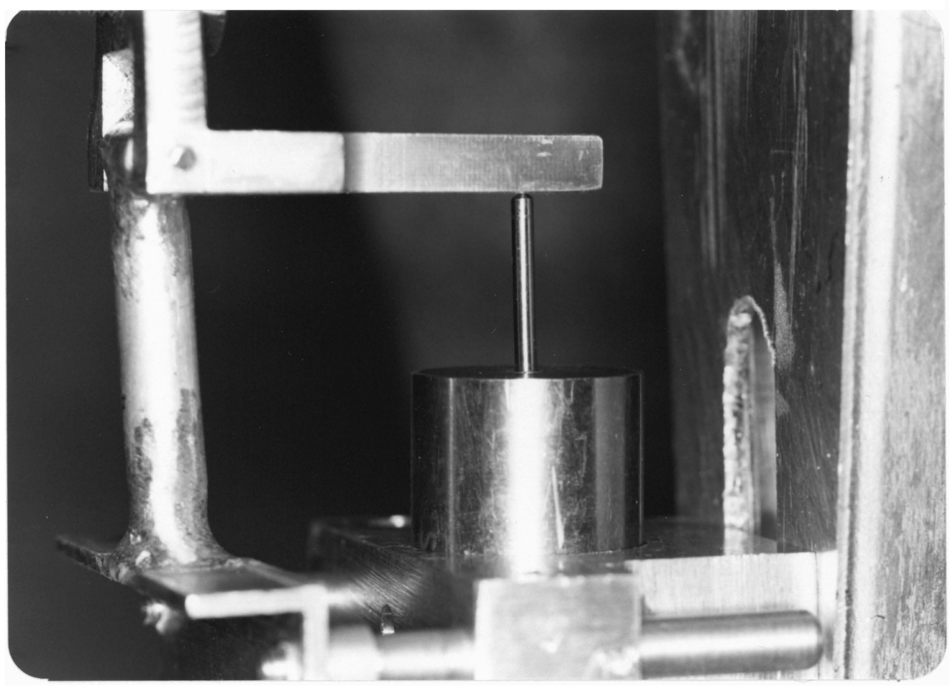


FIGURE 3

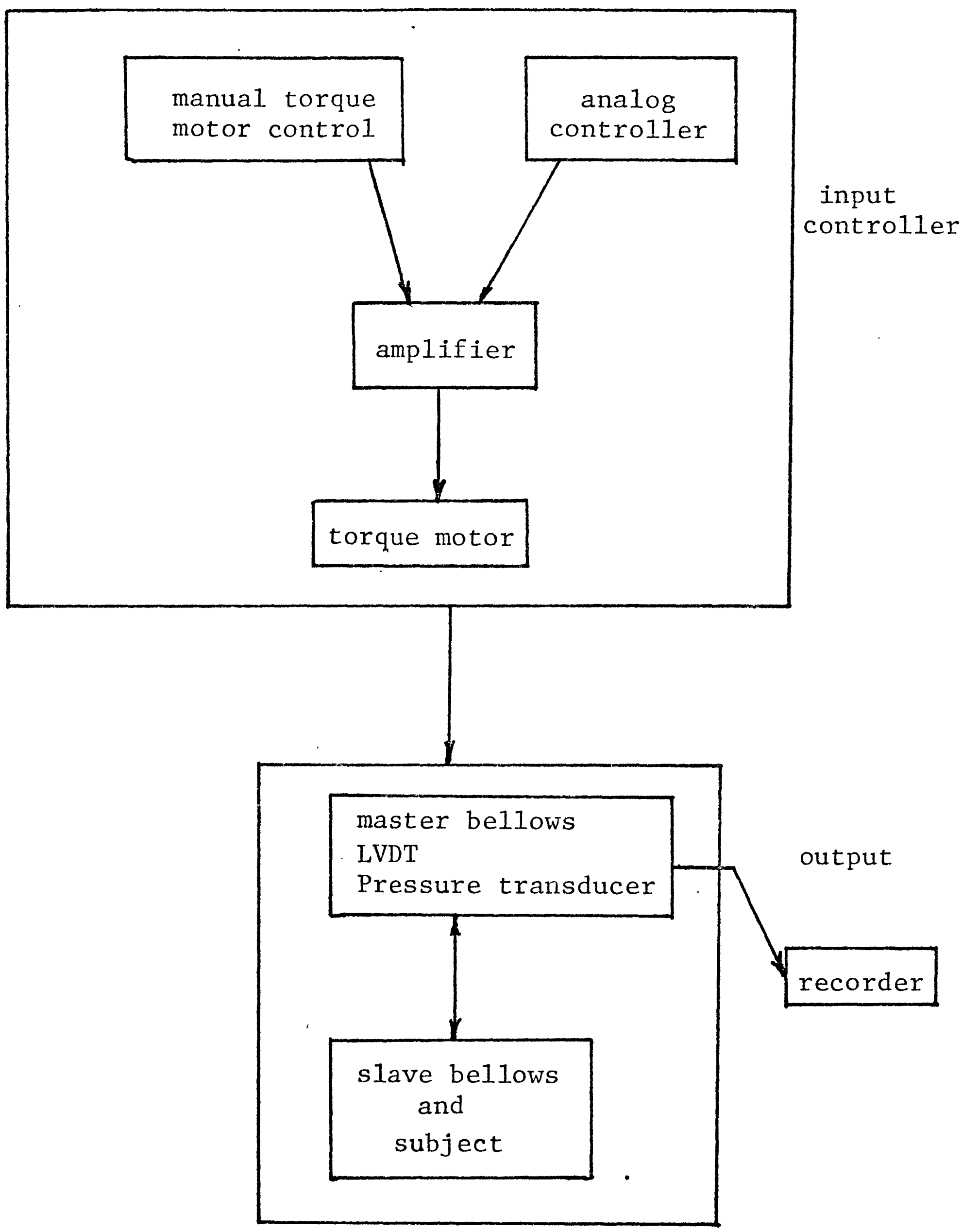
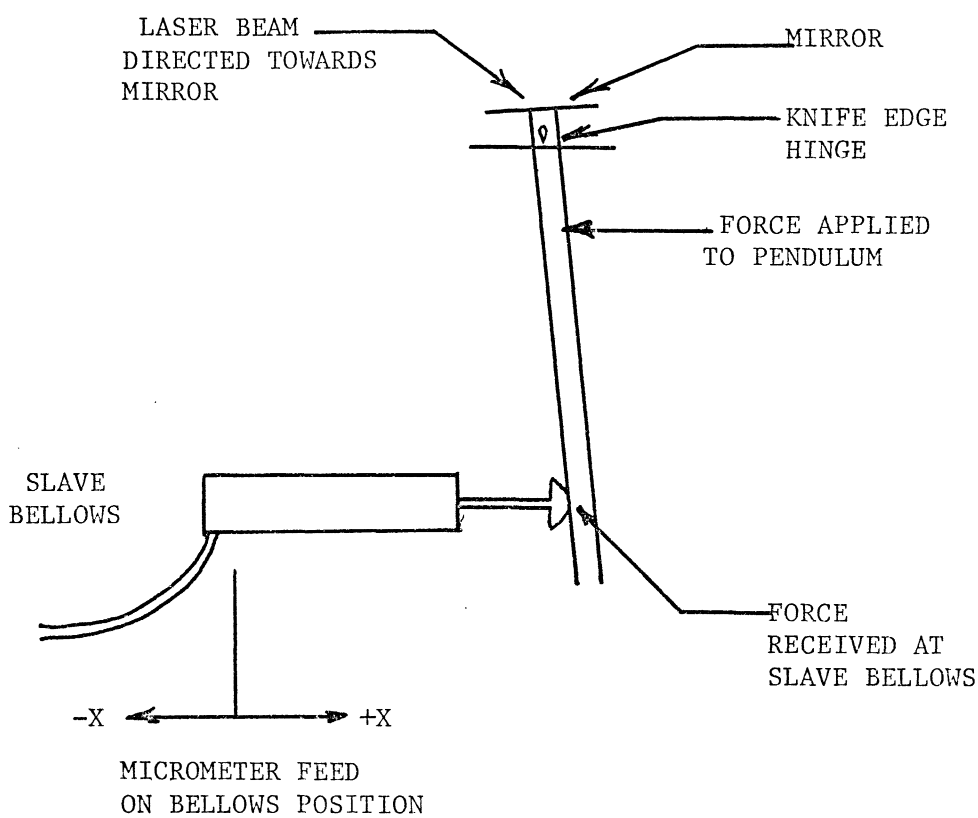

manual torque
motor control
analog
controller
input
controller
amplifier
torque motor
master bellows
LVDT
Pressure transducer
output
recorder
slave bellows
and
subject

FIGURE 4




A vertical pendulum can be loaded with known weights. The bellows to be calibrated is positioned against the free end of the pendulum and advanced by a micrometer feed. A laser beam is reflected off a mirror on the top of the pendulum to optically align the loaded pendulum in a true vertical position.

FIGURE 5

is first set equal to 0 grams. The master bellows is activated via the torque motor until it just contacts the pendulum which indicates displacement via a laser amplification beam. This is then defined as a 0 displacement. The slave bellows is then axially loaded from 0 to 50 grams and at each 10 gram interval the pendulum is brought back to the 0 point by means of the torque motor controller. This procedure is repeated in 0.5 millimeter increments in order to calibrate the entire range of the slave bellows. Thus a set of calibration curves is developed. A reverse procedure is used for developing unloading calibration curves because of hysteresis which is an inherent characteristic of the hydraulic system.

The second problem which arises is one of power input control of the torque motor. This is complicated by the non-linear characteristics of the torque motor. The torque motor control system consists of two parts: a manual controller of the input power to the torque motor and an analog controller which gives repeatable input desired for taking data.

The input characteristics are: 1) a linearly increasing voltage of preset peak voltage and ramping time (rate of loading); 2) a plateau period during which peak voltage is kept constant for a preset time interval; and 3) a linearly decreasing voltage with a preset slope and ramping time (rate of unloading).

The output is a linearly increasing displacement of the slave bellows, a period of constant displacement, and a linearly decreasing displacement of the slave bellows.

## Experimental Procedures

An alginate impression was made for each subject. A stone model was poured, and a removable appliance was fabricated. The slave bellows was mounted in such a manner as to place the acrylic button in the molar-premolar embrasure just lingual to a plane of the buccal surfaces between the molar and premolar. The subject was positioned comfortably in a dental chair and was instructed to remain immobile during each testing cycle. In order for the bellows to operate freely, it was necessary to have the subject maintain a jaw opening of approximately 6 - 7 mm. This dimension is slightly more than the resting interocclusal distance of most individuals. The opening position was fixed by having the subject gently contact a hard rubber bite block with both jaws. Soft tissue relaxation was demonstrated clinically.

Each subject underwent a series of 10 cycles. Each cycle consisted of activation, plateau, and deactivation. Cycles 9 and 10 for all subjects were utilized to test tissue characteristics with the head posture extended forward so that the craniocervical angulation to a vertical increased approximated 20 degrees (Figure 6). The following protocol was observed:

| Cycle Number | Up-Ramp Time | Plateau | Down-Ramp Time |
|---|---|---|---|
| 1 | 90 seconds | 1 minute | 45 seconds |
| 2 | 90 seconds | 1 minute | 45 seconds |
| 3 | 90 seconds | 1 minute | 45 seconds |
| 4 | 90 seconds | 1 minute | 45 seconds |
| 5 | 90 seconds | 4 minutes | 45 seconds |
| 6 | 90 seconds | 4 minutes | 45 seconds |
| 7 | 90 seconds | 4 minutes | 45 seconds |
| 8 | 90 seconds | 4 minutes | 45 seconds |
| 9 | 90 seconds | 12 seconds | 45 seconds |
| 10 | 90 seconds | 12 seconds | 45 seconds |

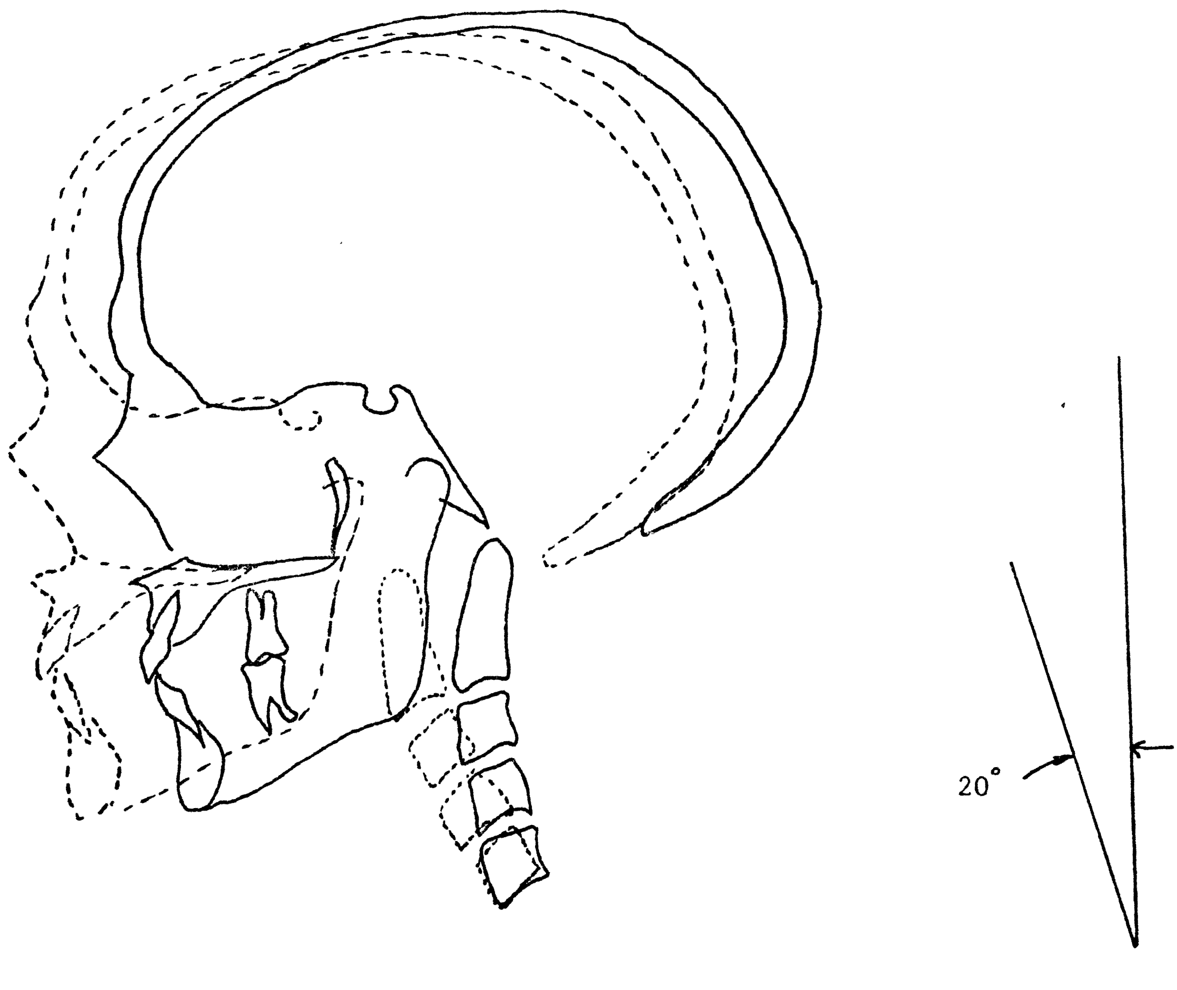



FIGURE 6

The cheek was held away from the slave bellows in order that no initial contact was present, tension on the torque motor was adjusted, the cheek released and the cycle was then initiated.

The data acquisition process was computer controlled (Computer Automation, Model # Alpha 16). Computer programs were written for system calibration, data acquisition, data analysis, and the resulting force-displacement graphs.

## Results

Stiffnesses were obtained by fitting a "best trend" line as a representative of the force-displacement slope. Up-ramp cycling with a one minute plateau yielded a mean stiffness of 1.16 $\pm$ 0.669 gm/mm with a range of 0.526 to 2.16 gm/mm. The down-ramp mean stiffness was 0.826 $\pm$ 0.568 gm/mm with a range of 0.135 to 1.75 gm/mm. Subject 2 demonstrated the highest up and down stiffness while subject 6 possessed the lowest mean stiffness for up-ramp displacement and subject 5 possessed the lowest mean stiffness for the down-ramp (refer to Tables I and IV). Up-ramp force ranges at 6 mm displacement of the bellows were 1.25 to 20.0 grams. Down-ramp forces ranged between 1.25 and 11.3 grams to its same bellows displacement (refer to Table VII).

The mean stiffness for up-ramp cycling with a 4 minute plateau was 1.38 $\pm$ 0.738 gm/mm with a range of 0.469 - 2.62 gm/mm. The down-ramp mean stiffness was 1.29 $\pm$ 0.613 gm/mm with a range of 0.460 to 2.12 gm/mm. Subject 2 demonstrated the greatest mean stiffness for both displacement ramps while subjects 3 and 6 possessed the lowest mean stiffness for the cycled ramps (refer to Tables II and V).

TABLE I Mean Stiffness values at a 0.06 mm/sec loading displacement followed by a stress relaxation for one minute

| subject number | mean stiffness,k (grams/millimeter) | S.D. | range |
|---|---|---|---|
| 1 | 1.02 | 0.240 | 0.833-1.34 |
| 2 | 2.16 | 0.259 | 1.89-2.5 |
| 3 | 0.982 | 0.341 | 0.753-1.49 |
| 4 | 2.06 | 0.473 | 1.57-2.61 |
| 5 | 0.742 | 0.265 | 0.458-0.983 |
| 6 | 0.526 | 0.226 | 0.202-0.706 |
| 7 | 0.660 | 0.400 | 0.187-1.06 |

TABLE II Mean Stiffness values at a 0.06 mm/sec loading displacement followed by a stress relaxation for four minutes

| subject number | mean stiffness,k (grams/millimeter) | S.D. | range |
|---|---|---|---|
| 1 | 1.25 | 0.253 | 1.00-1.48 |
| 2 | 2.62 | 0.331 | 2.29-2.98 |
| 3 | 0.771 | 0.239 | 0.437-0.965 |
| 4 | 1.98 | 1.19 | 0.466-3.06 |
| 5 | 1.02 | 0.414 | 0.723-1.31 |
| 6 | 0.469 | 0.221 | 0.313-0.625 |
| 7 | 1.53 | 0.258 | 1.31-1.89 |

TABLE III Mean Stiffness values for head extension posture at a 0.06 mm/sec loading displacement followed by a stress relaxation for 12 seconds

| subject number | mean stiffness, k (grams/millimeter) | S.D. | range |
|---|---|---|---|
| 1 | 1.36 | 0.399 | 1.34-1.38 |
| 2 | 0.610 | 0.316 | 0.387-0.833 |
| 3 | 0.749 | 0.070 | 0.688-0.809 |
| 4 | 2.84 | 0.699 | 2.34-3.33 |
| 5 | 0.747 | 0.564 | 0.348-1.15 |
| 6 | 0.920 | 0.222 | 0.764-1.08 |
| 7 | * | * | * |

TABLE IV Mean Stiffness values at a 0.13 mm/sec unloading ramp following a stress relaxation for one minute

| subject number | mean stiffness, k (grams/millimeter) | S.D. | range |
|---|---|---|---|
| 1 | 0.893 | 0.237 | 0.584-1.09 |
| 2 | 1.75 | 0.836 | 0.925-2.62 |
| 3 | 0.445 | 0.261 | 0.233-0.809 |
| 4 | 1.40 | 0.703 | 0.639-2.33 |
| 5 | 0.135 | * | * |
| 6 | 0.618 | 0.422 | 0.146-0.916 |
| 7 | 0.544 | 0.393 | 0.146-0.932 |

* no data

TABLE V Mean stiffness values at a 0.13 mm/sec unloading ramp following a stress relaxation for four minutes.

| subject number | mean stiffness, k (grams/millimeter) | S.D. | range |
|---|---|---|---|
| 1 | 1.42 | 0.899 | 0.833-2.75 |
| 2 | 2.12 | 0.493 | 1.45-2.62 |
| 3 | 0.460 | 0.434 | 0.182-1.09 |
| 4 | 1.00 | 0.487 | 0.340-1.51 |
| 5 | * | * | * |
| 6 | * | * | * |
| 7 | 1.44 | 0.287 | 1.15-1.83 |

TABLE VI Mean stiffness values for head extension posture at a 0.13 mm/sec unloading ramp following a stress relaxation for 12 seconds

| subject number | mean stiffness, k (grams/millimeter) | S.D. | range |
|---|---|---|---|
| 1 | 1.03 | 0.044 | 1.00-1.06 |
| 2 | * | * | * |
| 3 | * | * | * |
| 4 | 1.52 | 0.539 | 1.13-1.90 |
| 5 | * | * | * |
| 6 | 0.745 | 0.006 | 0.705-0.786 |
| 7 | * | * | * |

* no data

TABLE VII Maximum Force(grams) at 6mm displacement

| | subject 1 | | subject 2 | |
|---|---|---|---|---|
| run # | up-ramp | down-ramp | up-ramp | down-ramp |
| 1 | 9 | 3 | 8.3 | 7.5 |
| 2 | 5 | 4.5 | 10 | 6.5 |
| 3 | 3 | 3 | 10 | 3.7 |
| 4 | 5 | 3.4 | 12.5 | 7.5 |
| 5 | 5.6 | 4 | 10 | 5.3 |
| 6 | 5 | 4.4 | 9.7 | 5.9 |
| 7 | 6.75 | 5.63 | 10.9 | 5 |
| 8 | 6.13 | 6.13 | 11.88 | 4.4 |
| 9 | 7.5 | 6.8 | 5 | * |
| 10 | 6.8 | 6.8 | 2.5 | * |

| | subject 3 | | subject 4 | |
|---|---|---|---|---|
| 1 | 6.3 | 1.6 | 9.4 | 6.3 |
| 2 | 5 | 1.5 | 14 | 6.8 |
| 3 | 3.75 | * | 11.3 | 6.8 |
| 4 | 3.7 | 3.7 | 17.5 | 11.3 |
| 5 | 3.7 | 2 | 12.5 | 9.4 |
| 6 | 5 | .63 | 5 | 8.1 |
| 7 | 3.75 | 1.5 | 25 | 12.5 |
| 8 | 3.2 | 2 | 19 | 13 |
| 9 | 4.5 | 4.5 | 24 | 9 |
| 10 | * | * | 14 | 8.8 |

| | subject 5 | | subject 6 | |
|---|---|---|---|---|
| 1 | 3.75 | 1.25 | 1.25 | * |
| 2 | 5.63 | * | 2.5 | 1.88 |
| 3 | 20 | * | 2.5 | 1.25 |
| 4 | 5 | * | * | * |
| 5 | 30 | * | .63 | .63 |
| 6 | 3.8 | * | 1.88 | * |
| 7 | 20 | * | * | * |
| 8 | 5 | * | .63 | * |
| 9 | 5 | * | .63 | * |
| 10 | 6.7 | * | 3.13 | 2.5 |

* no data

TABLE VII CONT'D

subject 7

| run # | up-ramp | down-ramp |
|---|---|---|
| 1 | 2.5 | * |
| 2 | 3.5 | 3.5 |
| 3 | 1.3 | 1.3 |
| 4 | 4.4 | 3.8 |
| 5 | 5.6 | 3.1 |
| 6 | 6.8 | 5 |
| 7 | 5.5 | 5 |
| 8 | 5.6 | 5 |
| 9 | * | * |
| 10 | * | * |

* no data

Forces ranged from 0.63 to 25 grams at 6 mm displacement for the up-ramp activations while down-ramp forces ranged from 0.63 to 12.5 grams at 6 mm displacement (Table VII).

Up-ramp mean stiffness for head posture extension was 1.22 $\pm$ 0.878 gm/mm; for down-ramp, 1.10 $\pm$ 0.391 gm/mm. Respective up and down ranges were from 0.61 $\pm$ 1.36 gm/mm and from 0.745 to 1.52 gm/mm. Subjects 4 and 2 demonstrated the highest and lowest mean stiffness respectively for up-ramp cycling while subjects 1 and 6 possessed the highest and lowest mean stiffness respectively for down-ramp cycling (Tables III and VI). Forces ranged from 2.5 to 24 grams at 6 mm displacement for up-ramp and from 2.5 to 9 grams for down-ramp (refer to Table VII).

Resting force measurements suggest a range between 0.1 to 0.5 grams, however, the limited accuracy in defining this measure tempers the analytical findings. No analysis was therefore made of resting force.

## Discussion

In order to establish a value for a resting force it is of the utmost importance to first define it. Most investigators (Proffit, 1964; Jacobs, 1967; Lear and Moorrees, 1969) have arbitrarily selected points of reference to define forces associated with tissue at rest. The present study suggests that resting forces are difficult to define, and subsequently extremely difficult to measure. Resting force might be defined as the force measured upon initial contact of the cheek tissue to tooth surface or as the force assessed at a known displacement. This study chose to define resting force as that force measured upon initial contact between tooth surface and tissue surface. They system of measurement, its sensitivity and instrumentation have thus far limited the assessment of this initial contact. At the present time it is not appropriate to state precisely the magnitude of the "resting force" in the premolar-molar region.

The physical property of tissue extensibility indicated that the tissue tested was stiffer than had been determined by Etzelmiller (1963). Etzelmiller assessed stiffness at the subject's cheek resting force. As illustrated in the extensibility graph (see Appendix I) the force-displacement values determined from the present study were slightly lower than those of the former study. Instrumentation differences may account for these discrepancies. In addition, the resting force could not be obtained from subjects with complete dentitions because it was necessary to go beyond the projected intermaxillary resting space due to the bulk of the slave bellows. However, distances for the intermaxillary space were similar in all subjects. The slave bellows apparatus was difficult to orient perpendicular to the cheek due to the bellows length and the space limitation of the palate. Hence, measurement was recorded at an angular displacement, therefore not normal to the cheek. Angulation ranged between 75 and 100 degrees perpendicular to the cheek.

Studies of cat tendon (Ellis, 1970) demonstrated that one of the effects of repeated cyclic loading was that the strain response approached a steady state. The load-elongation recording for each cycle was a closed loop and the area within the loop was representative of energy dissipation. This hysteresis energy loss was demonstrated in the present study. A quantitative measurement was not possible because of the inherent instrumentation noise superimposed upon the apparent force perturbations from the tissue being tested. The interference was demonstrated as the displacement cycle force spiking which was detected upon examination of the force displacement curves (see Appendix II). It suggested that the spiking was an amplification of the complex tissue response emanated from the cheek. The buccinator muscle, oral mucosa, the teeth and the connective tissues and adipose tissues of the skin contribute to the complex response. The cheek is a complex of many specialized soft tissues. Externally there is an integument which extends in all directions along the head and neck region, under this lies the buccinator muscle enveloped by fascia, the buccal glands and mucous membrane internally. In addition, there are varying quantities of fat tissue as well as vessels, and nerves. Moreover, this complex is contiguous with structures superiorly, inferiorly, anteriorly, and posteriorly. Hence, it would be incorrect to assume one is examining only muscle. Environmental factors, including the individual's personality, should be examined. It seems probable, therefore, that force perturbation can be considered a characteristic of the quality of the cheek since a multiplexity of components comprise the perioral tissue. It is also possible that certain spikes resulted from the tongue contact upon the slave bellows.

Most studies of muscle properties imply that the force generated in contact with the dentition was attributed to muscle or musculature.

Connective tissue studies and studies of skin (Haut and Little, 1972; Kenedi, et al., 1964; Smith, 1954) demonstrated that tissue load-deformation properties were similar to the patterns seen in the present investigation.

A comparison of rubber dam material was utilized to test for system noise (Figure 7). The force-displacement plot shows that the spiking which occurred was small, indicating that the noise inherent in the instrumentation was not a major contributor to spiking seen in the data on the human subjects. The greater spiking that the cheek tissue demonstrated reasserts the complexity of the tissue.

Solow and Kreiborg (1977) suggested that "morphological changes observed with extension of the head could be caused by increase vertical and dorsal force components from the facial soft tissue layer subjected to stretching during long term extension of the head." As a result of the small sample size, the data from the present study does not support the previous statement.

## Conclusions

1. Resting force, defined as the initial contact of the cheek with the dentition, ranged between 0.1 and 0.5 grams in adolescents.
2. Hysteresis, a characteristic of viscoelastic materials, was observed in force-displacement cycling of adolescent cheek tissue.
3. Head posture extension may have an influence upon facial morphogenesis.

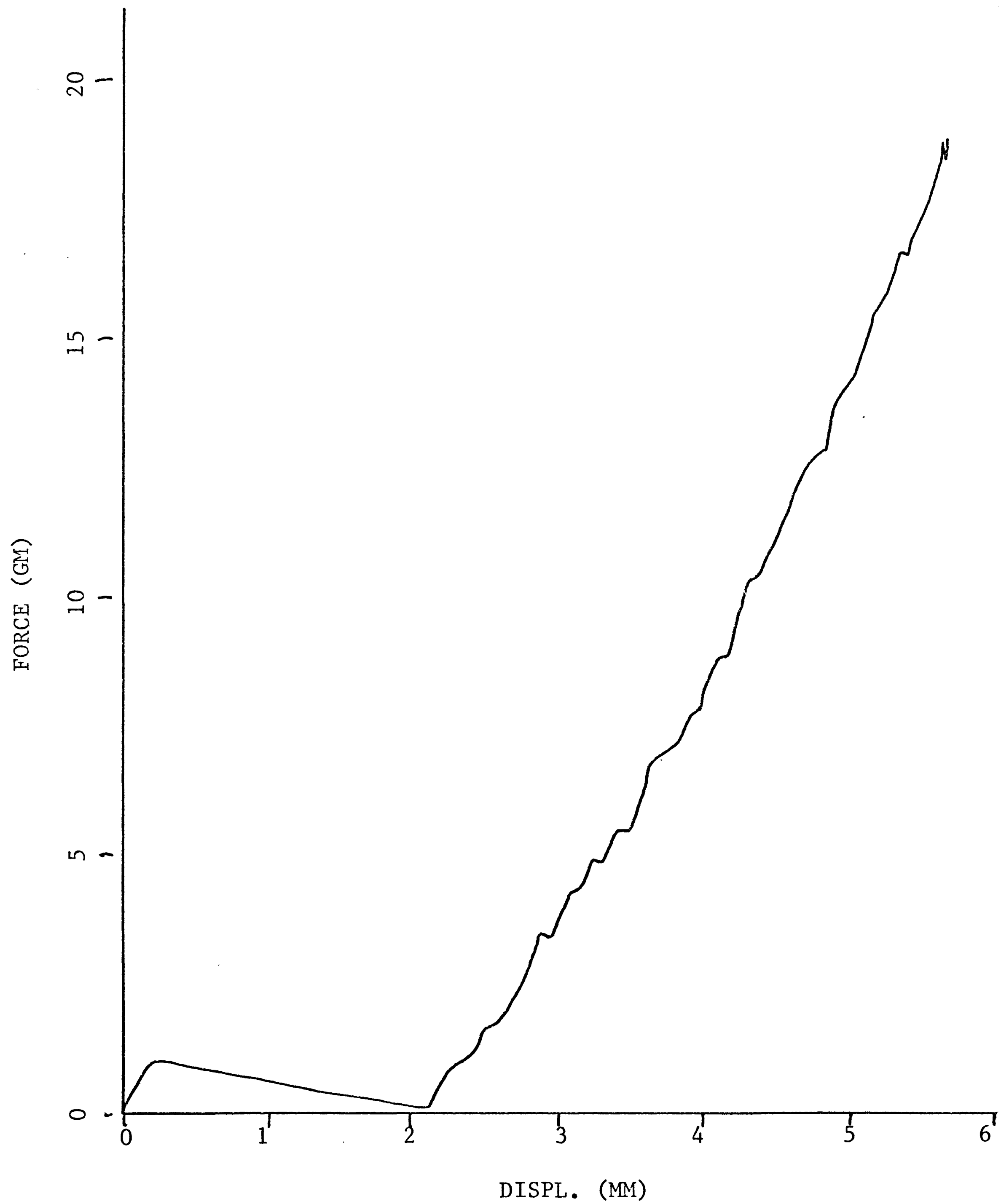
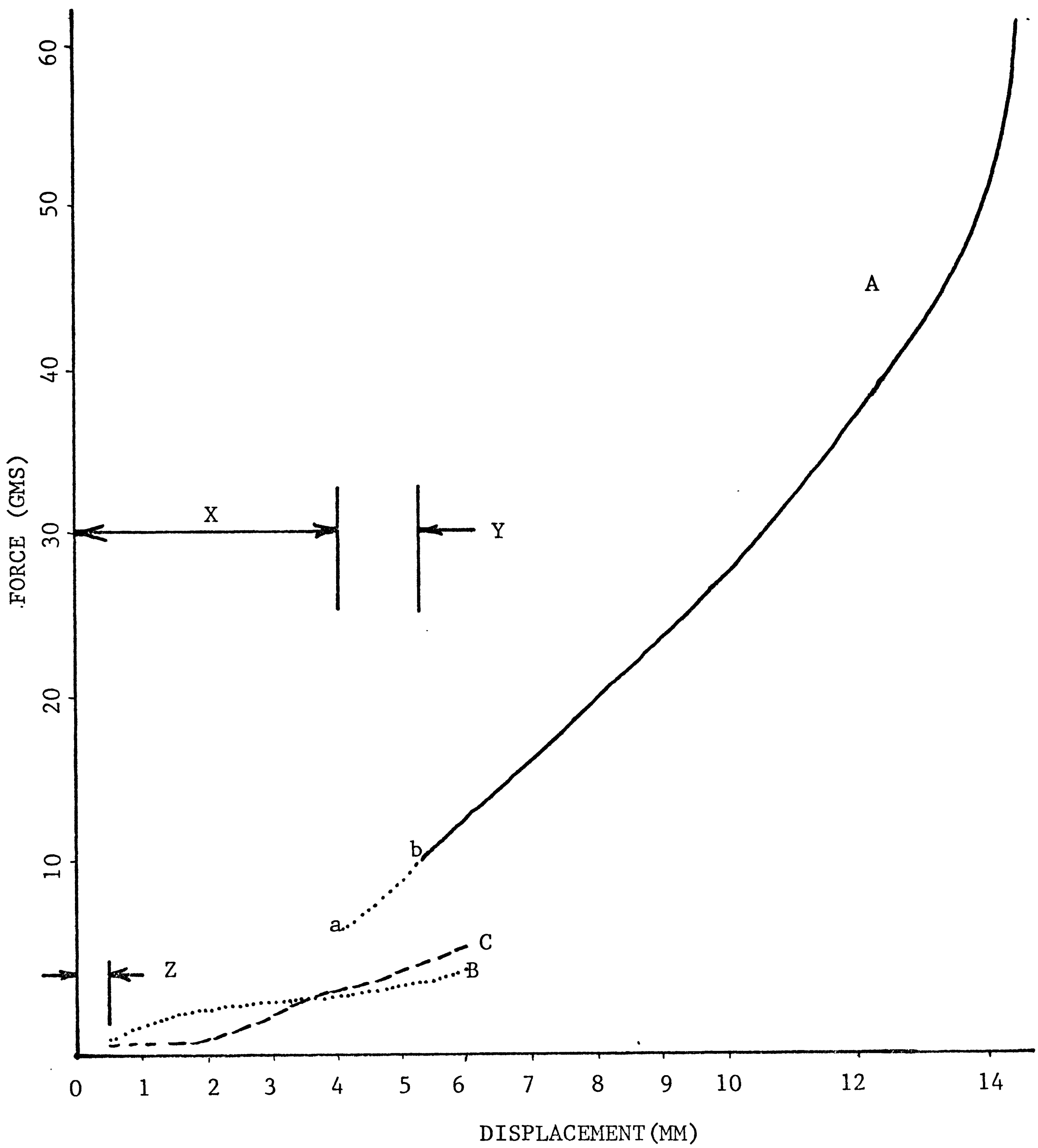



FIGURE 7

4. Force perturbations are an inherent characteristic of cheek tissue.
5. Cheek tissue is a complex of components each contributing to the overall stiffness quality.

# APPENDIX

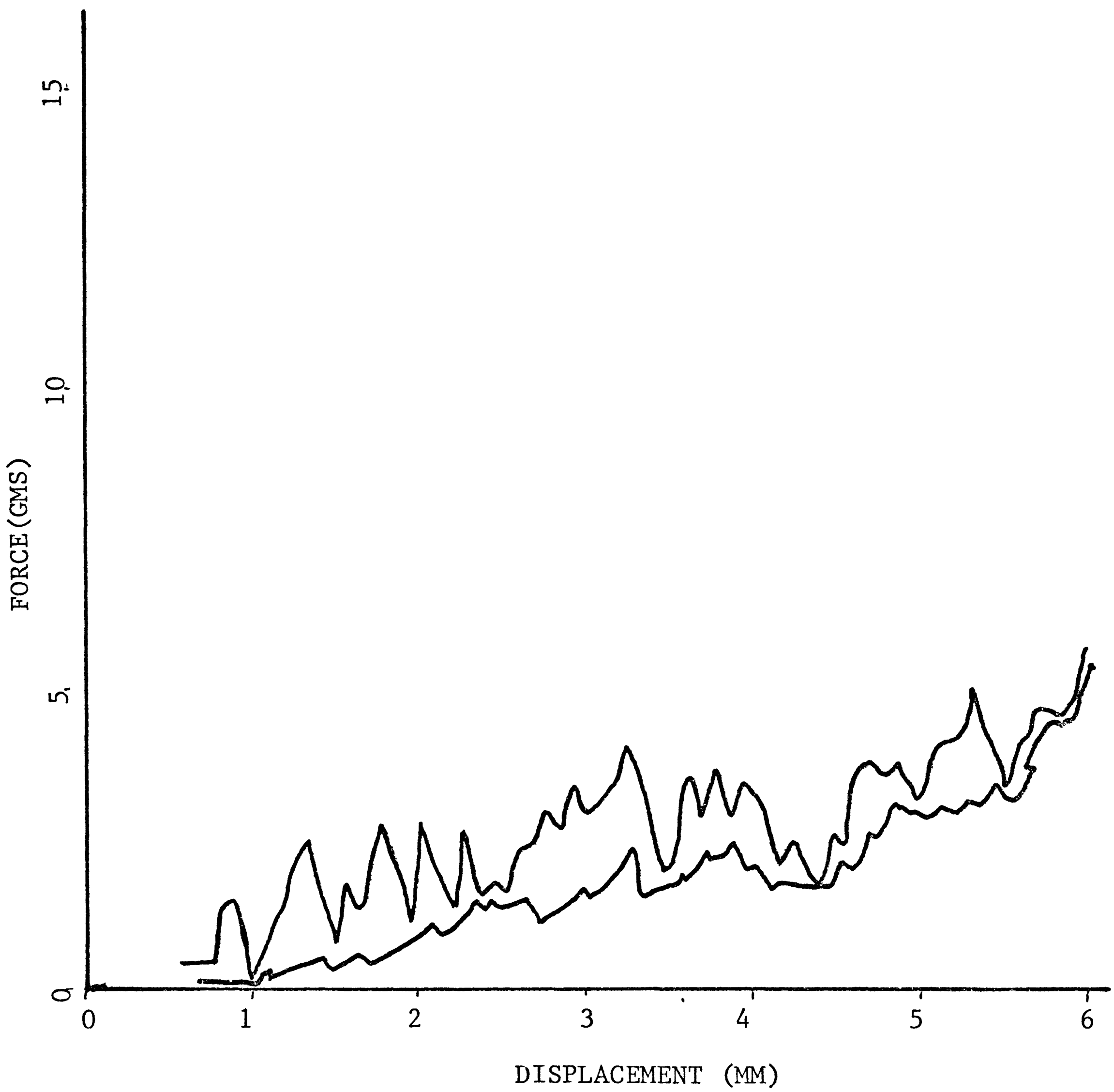
# APPENDIX I



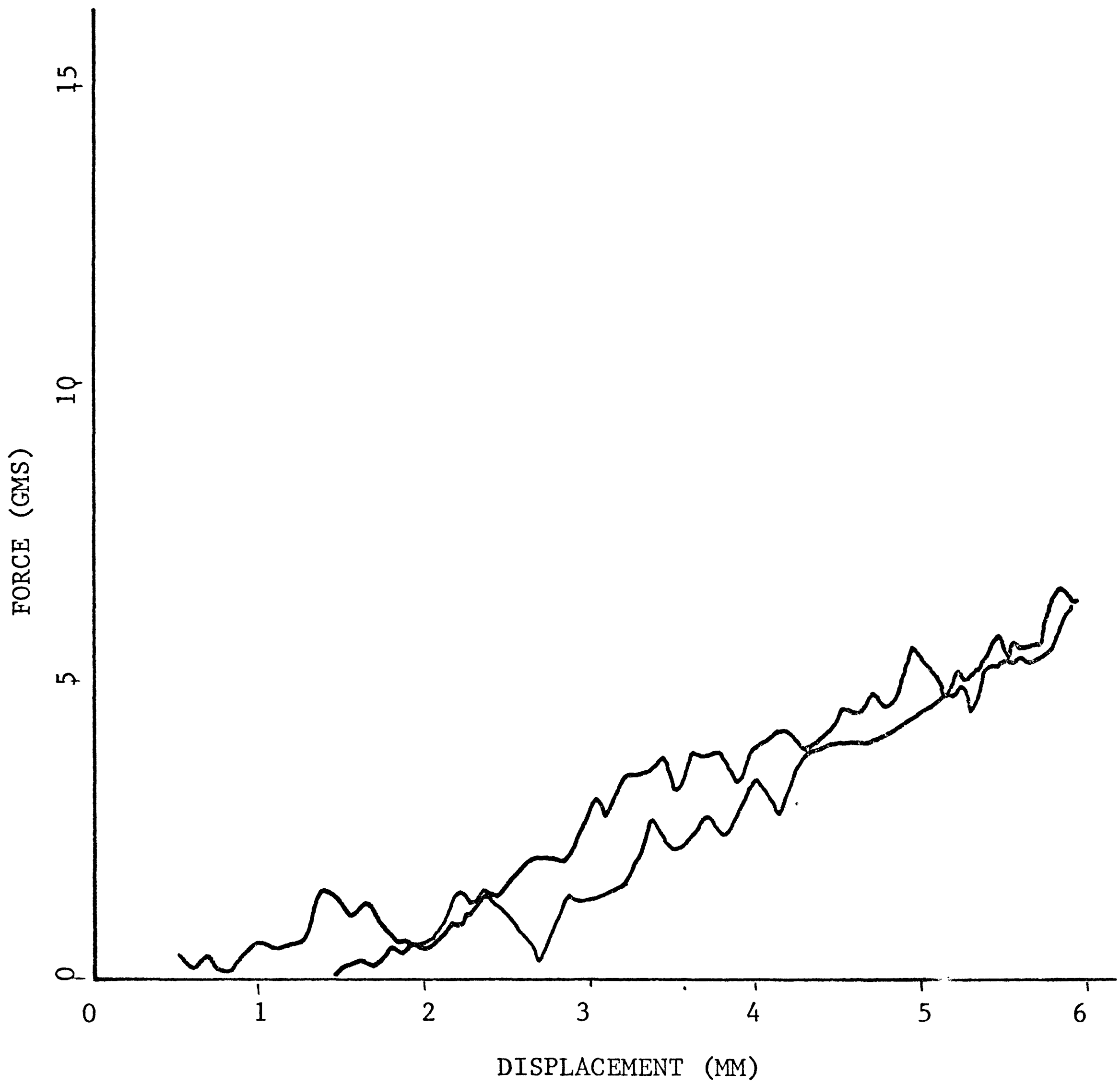

Extensibility Graph illustrating Etzelmiller's mean force-displacement for 40 individuals 12 to 16 years of age(A) compared to representative force-displacements from a 12 year old (B) and a 16 year old subject (C). (Actual force-displacement graphs for B and C are in Appendix II.

X= average button width used in Etzelmiller's study
Y= displacement interpolation from 0 gms(a) to 10.16 gms(b)
Z = no cheek contact with button

# APPENDIX II

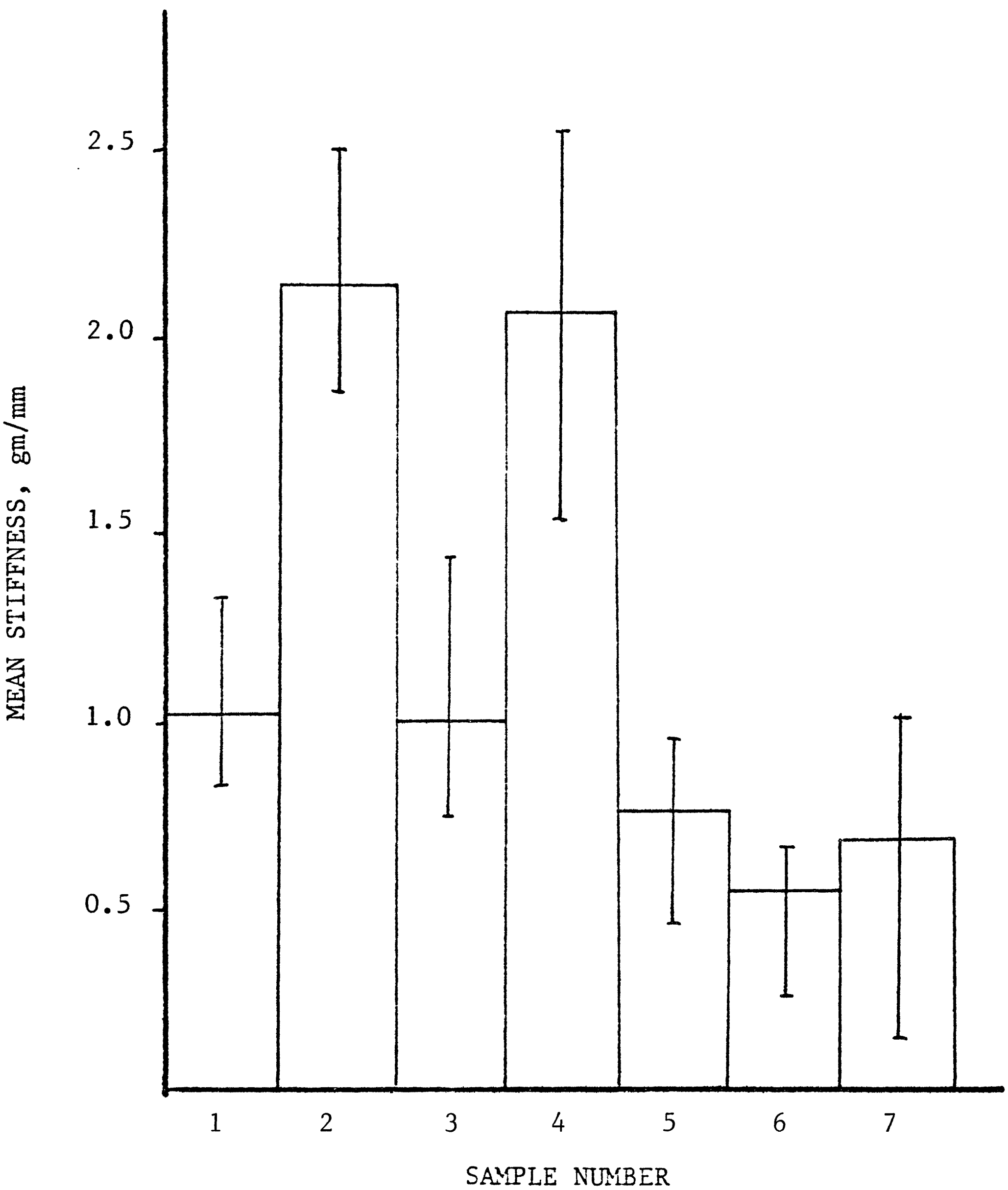



Force-Displacement Graph for Subject #5,run #2: 12 years old

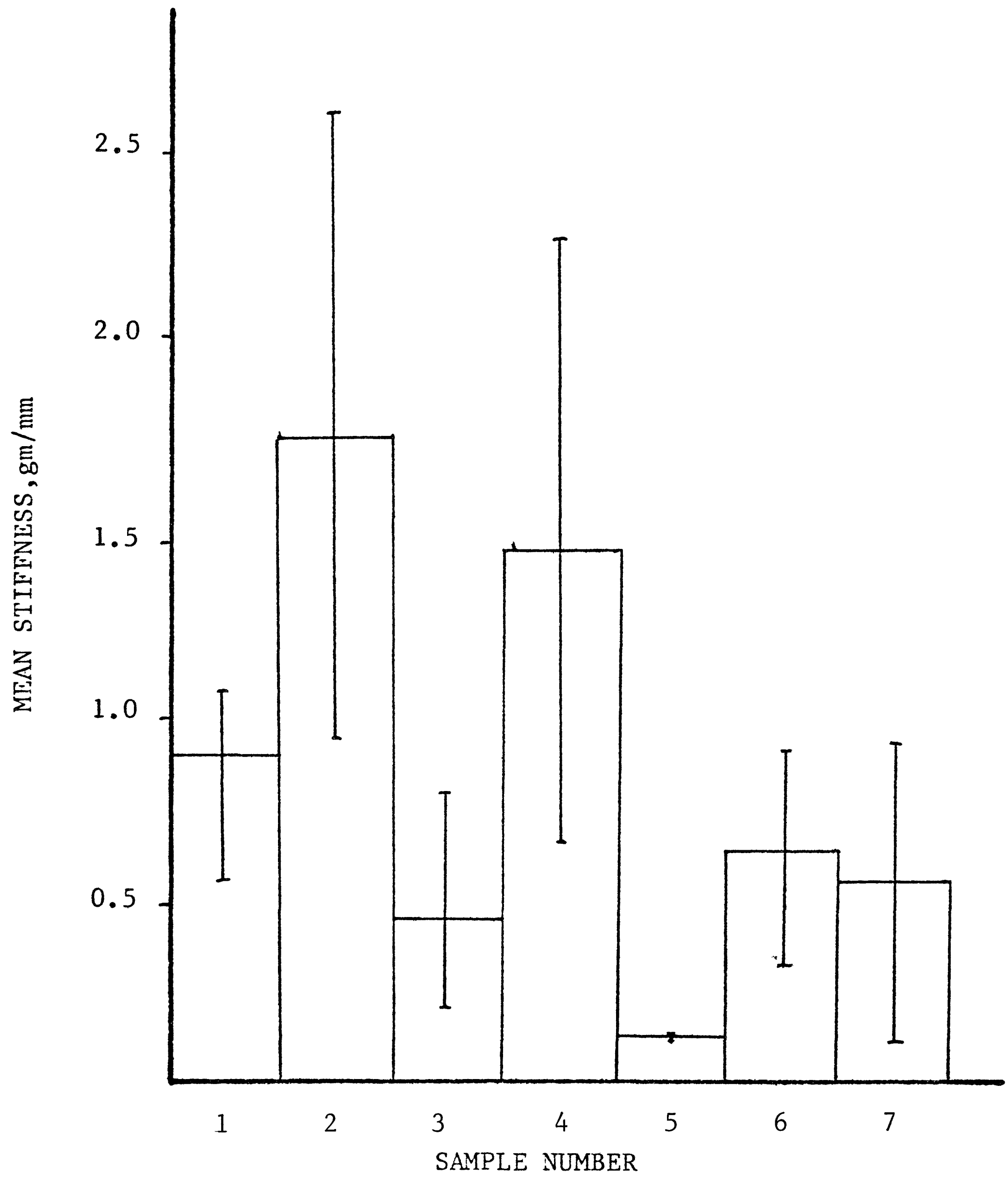



Force-Displacement Graph for Subject #1,run #8: 16 years old

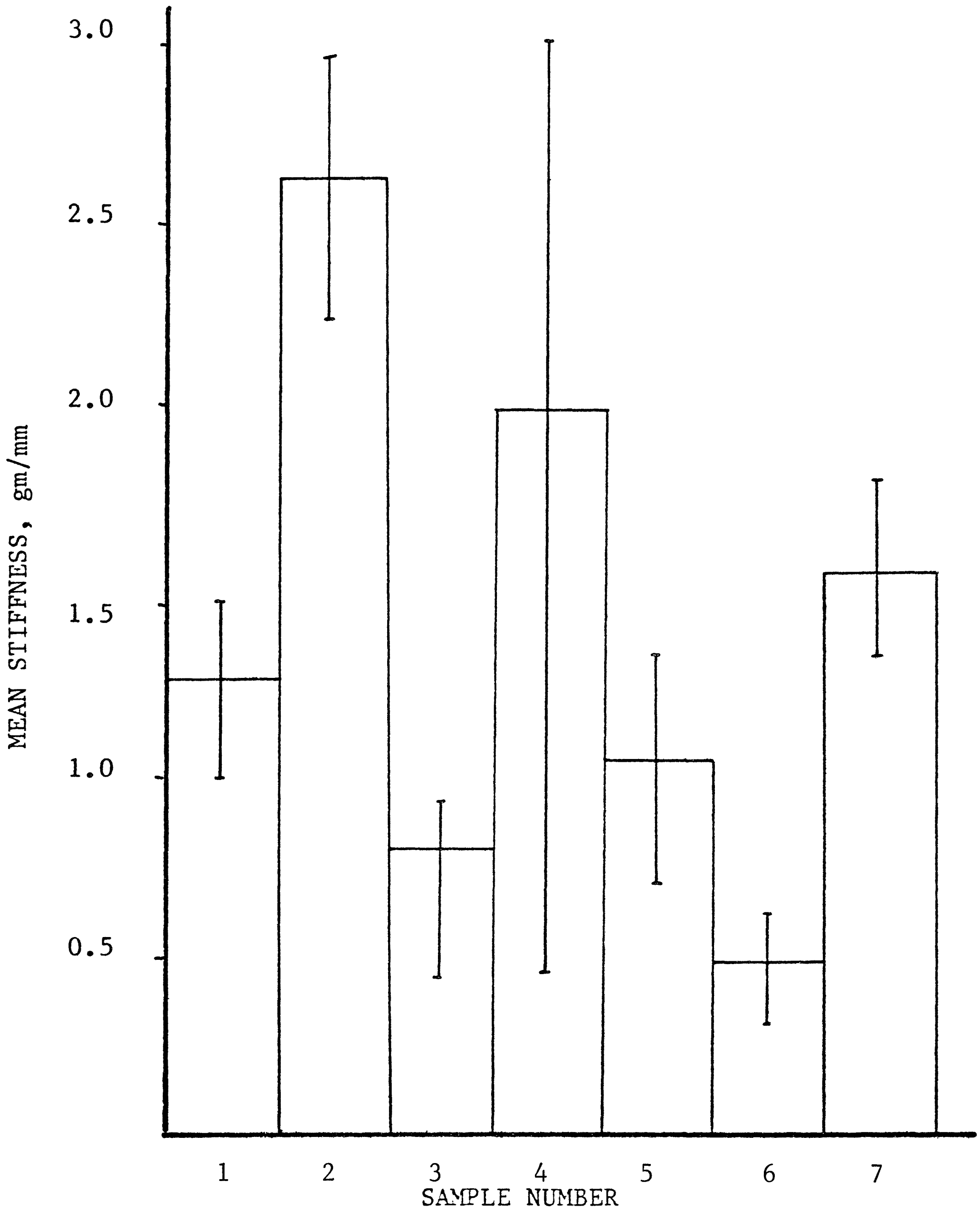
# APPENDIX III



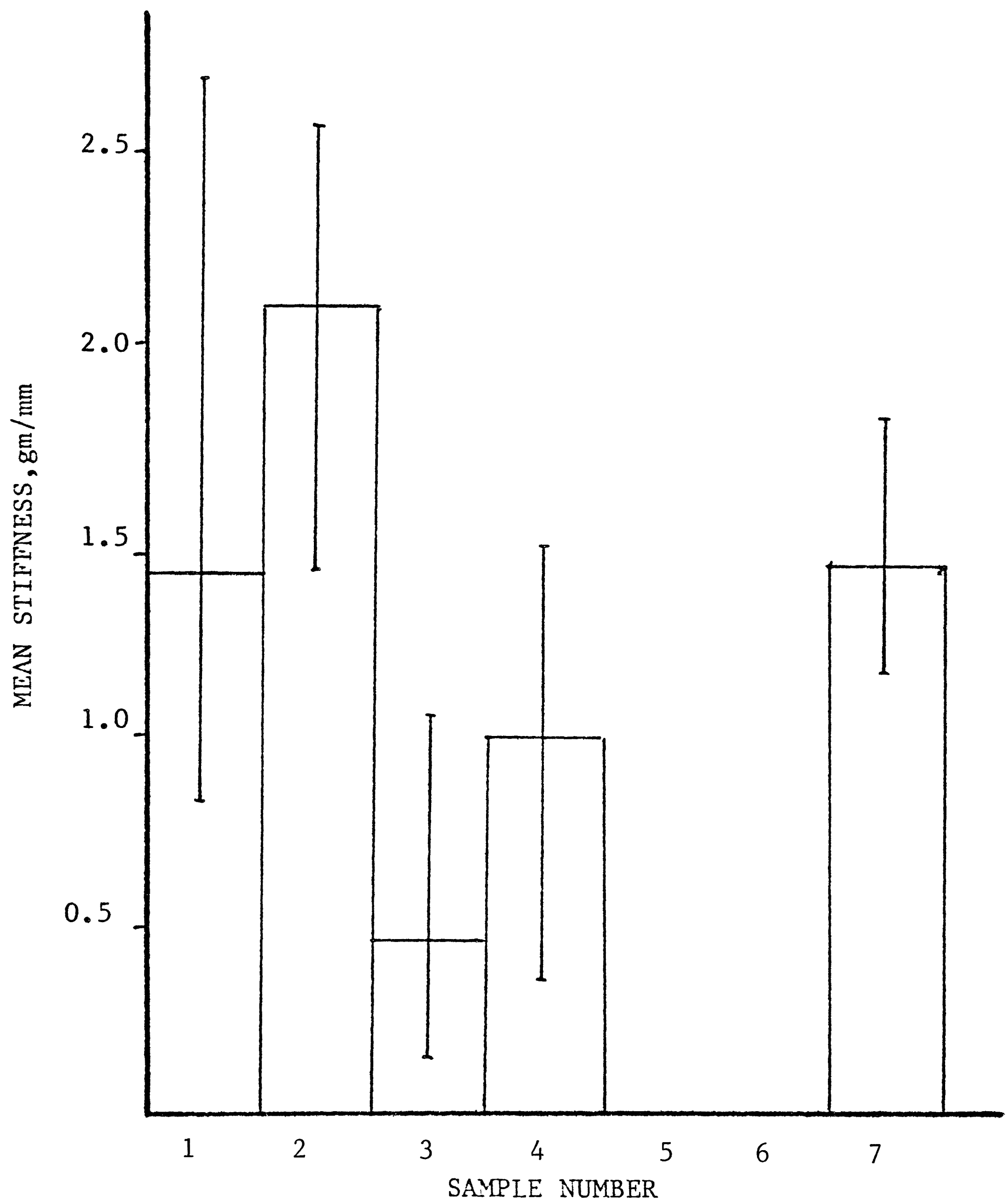

Bar Graph showing the distribution of mean stiffness values at a 0.06 mm/sec loading displacement followed by a stress relaxation for one minute



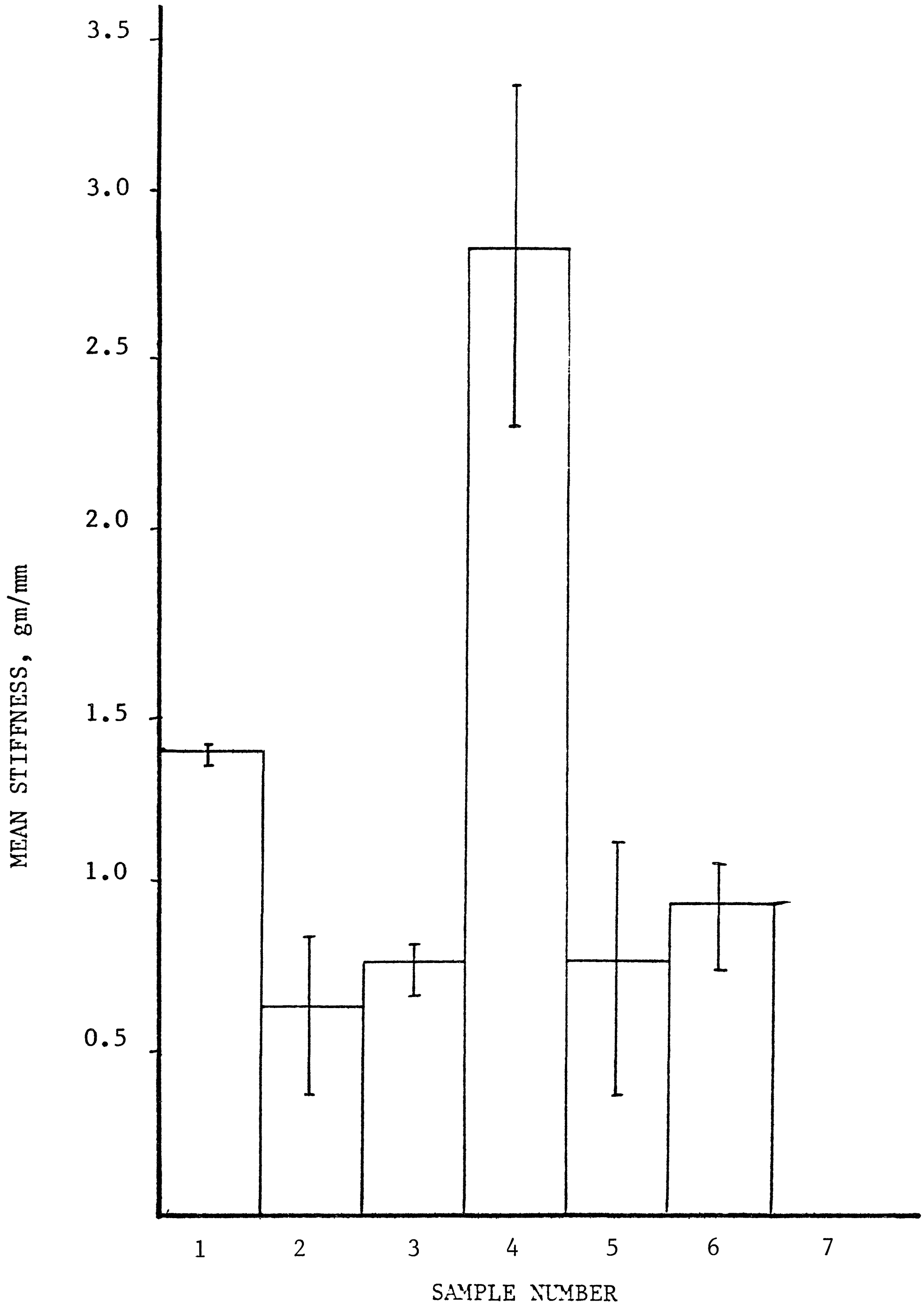

Bar Graph showing the distribution of mean stiffness values at a 0.13 mm/sec unloading ramp following a one min-stress relaxation



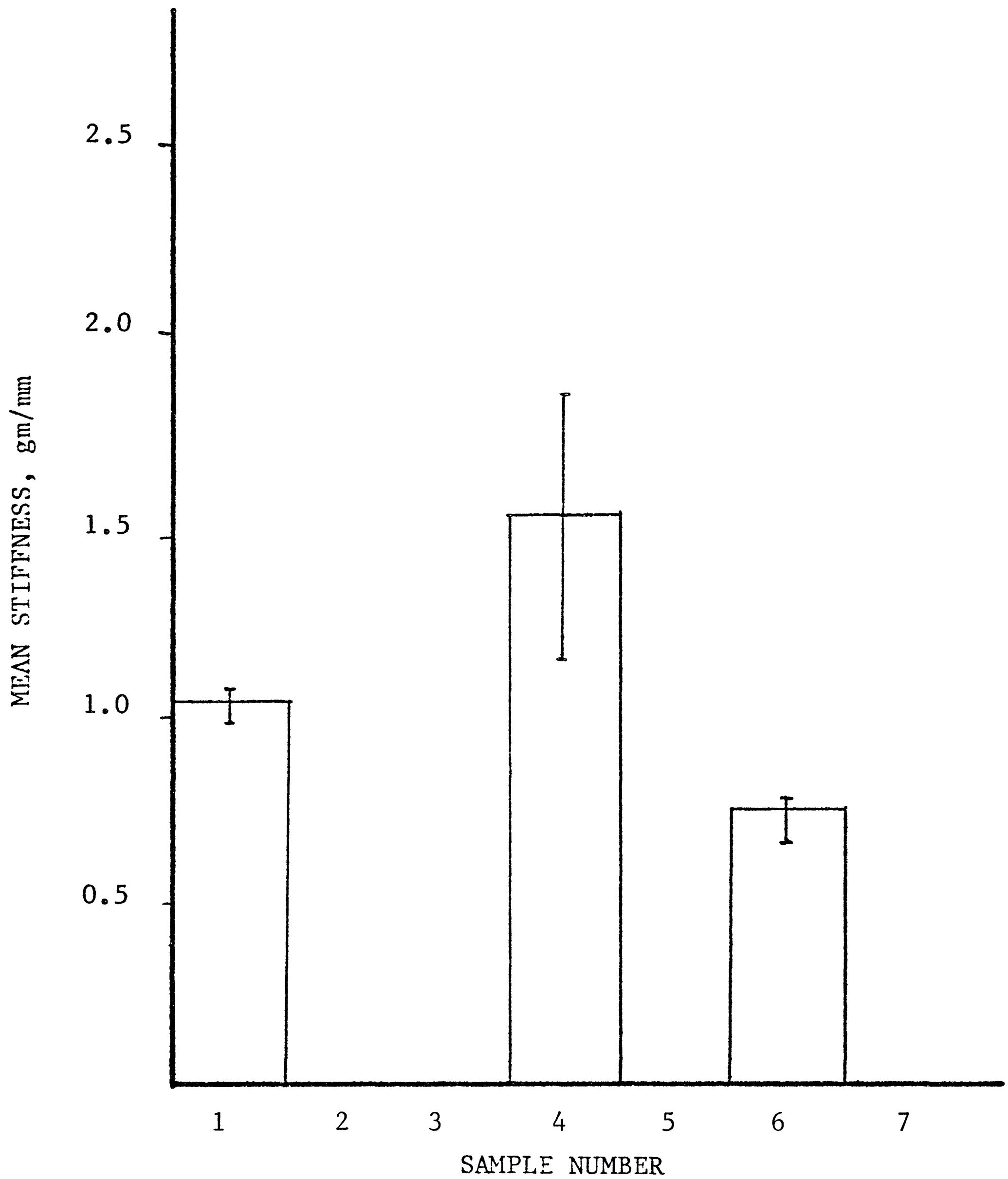

Bar Graph showing the distribution of mean stiffness values at a 0.06 mm/sec loading displacement followed by a stress relaxation for four minutes




Bar Graph showing the distribution of mean stiffness values at a 0.13 mm/sec unloading ramp following a four minute stress relaxation




Bar Graph showing the distribution of mean stiffness values for head extension posture at a 0.06 mm/sec loading displacement followed by a stress relaxation for 12 seconds




Bar Graph showing the distribution of mean stiffness values for head extension posture at a 0.13 mm/sec unloading ramp following a stress relaxation for 12 seconds

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